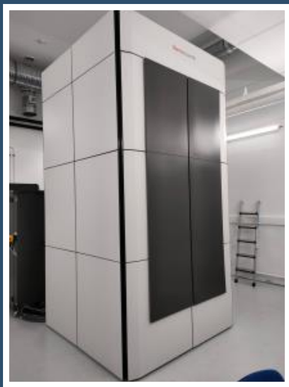
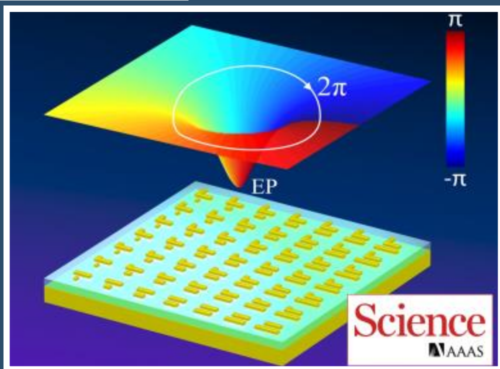
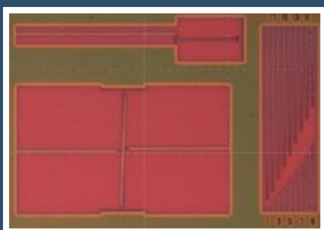
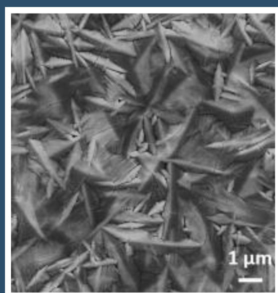
2021

UNE ANNÉE









EDITORIAL

One Editor's pick for 2021 could be the still on-going COVID crisis. It would be easy to insist on how difficult it is, not be overwhelmed by this heartbreaking atmosphere around us. With this COVID crisis, it is just like standing upon a cliff and we all know how compelling it can be to look below, towards the haze of the abyss. But our mission is certainly to bring imagination at the forefront. 2021 should not be remembered as one more COVID year but rather as a year of great success for CRHEA and for our community.

There have been some brilliant scientific results and this booklet is here to highlight them. One way to look at these results is to read the associated publications. These publications are obviously the core of our research activities. Another way to look at them is to see how the work we do at CRHEA can be inspiring for future research, for the people who drive the projects, for the people who put all their energies in innovative directions. It can even be inspiring for fiction worlds, at a time where fiction is so much needed. It is up to you to imagine the future that we build with our research efforts.

To obtain groundbreaking results, we do need some equipments, most of the time expensive equipments, but we need more importantly talented people. Plenty of them were already present at CRHEA but we can certainly say that 2021 has been a great year to attract new talents. Pierre-Marie Coulon, coming from Tyndall, has joined us at the beginning of the year. Minh Tuan Dau, former postdoc fellow at Spintec, has been hired by UCA as a new assistant professor and will boost the growth activity on 2D materials. Antoine Réserbat-Plantey from ICFO has been hired as CNRS research associate and should be with us at the beginning of 2022. CNRS Institute of Physics has given its green light for the mobility of François Dubin, presently at INSP.
It happens that people's talent is recognized by our institutions and independent jurys. Many others certainly deserve this recognition but we can warmly congratulate Julien Brault, Aimeric Courville and Sébastien Chenot for their recent promotions.

EDITORIAL

During 2021, CRHEA has reinforced its positions in ambitious programmes. The new transmission electron microscope is now ready for operation. A project to support our technology platform should start soon, in the framework of the so-called Contrat Plan État Région. A tender to buy a new MBE reactor for 2D materials is almost ready for publication, with the support of the Equipex+ programme NANOFUTUR. We expect CRHEA to be involved in the coming PEPR on electronics and in the application by UCA to the “Excellences sous toutes ses formes” PIA4 call.

The ties between CRHEA and UCA are stronger than ever. A first agreement has been reached between CNRS and UCA for the transformation of the lab into an “Unité Mixte de Recherche”. The lab’s council has given its full support to this initiative. Further detailed discussions between INP and UCA are now on track for the year 2022.
Our partnership is not only with university but as well with industry, large groups or small enterprises. Several PhD grants with industry as part of CIFRE agreements are under reviews. A new support has been provided by the “Plan de Relance” for CRHEA and EasyGaN. Transfer of innovation continues to be strong.

We are planning our future, we always are but 2021 was special. We had some great discussions during the year on our strategy towards 2025. General assemblies, laboratory days, internal discussions have provided the basis for a new organization to be unveiled in 2022. We look forward as well for the HCERES evaluation that will certainly take a great part of our energy in 2022.

Everything is in place to make Sparks in 2022.

So May We Start,

Philippe Boucaud
Director of CRHEA

2021 STATISTICS

63
people

35
publications in 2021

3 M€
budget without salaries

18
current ANR projects

6
european projects
(1 ERC)

46
patents

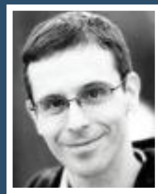
2
hosted companies
6 people

1
Labex coordination
(GaNexT)

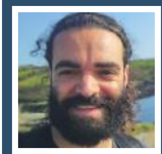
2021 EVENTS

January

Jean-Michel Chauveau left CRHEA and the Université Côte d´Azur (UCA) after 16 years and joined the Group for the Study of Condensed Matter (GEMaC) at the University of Versailles Saint-Quentin (UVSQ).



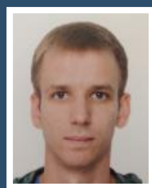
February



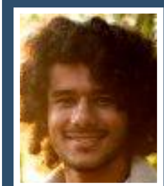
Pierre-Marie Coulon joined the Nano team after a post-doctorate at the University of Bath, then at the Tyndall National Institute in Cork (Ireland). He was recruited at CRHEA as a research engineer.

March

Nikita Nikitskiy joins the Nano - Metasurfaces team for a thesis under the direction of Julien Brault and Patrice Genevet. Subject: "Directional Light Emitting Metasurfaces of Quantum Dot Doped Element III Nitrides (AlGaN)".



May



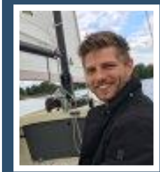
Reda El Waradi is starting a new PhD at CRHEA in the Electro team under the direction of Yvon Cordier. Subject: Development of aluminum-rich Element III nitride heterostructures for lateral power electronics.

June

CRHEA staff participated to a brainstorming meeting with the objective to determinate which aspect off the laboratory organisation has to be changed.

2021 EVENTS

June

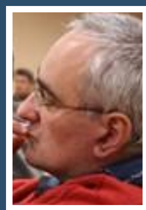


Philipp John defended his doctoral work on "Growth and characterization of Zn and Mg oxynitrides: from materials science to transistor fabrication".

Patrice Genevet defended his habilitation to supervise re-search (HDR) by presenting his work on “Contributions to the development of optical metasurfaces”.

August

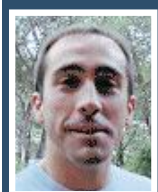
Patrick Chalbet has left CRHEA after more than 15 years of remarkable work. He’s starting a new career at IPMC.



September

Luan Nguyen has left CRHEA and starts a new career at the Laboratory of Computing, Signals and Systems (I3S) in Sophia Antipolis.

Minh Tuan Dau, assistant professor, is recruited into the Nano team.



Jesús Zúñiga-Pérez, researcher in the Nano team is spending a two years sabatical at Nanyang Technological University (NTU) in Singapore.

2021 EVENTS

October

CRHEA hosted a stand presenting its main activities within the framework of the Village des Sciences at the Palais des Congrès in Antibes Juan-les-Pins on October 15 and 16, 2021. A dynamic team from the laboratory animated these days by offering fun experiences and advanced experiments to a large audience.

Chiara Mastropasqua is starting a PhD at CRHEA in the Electro team under the direction of Adrien Michon.
Subject: Growth of graphene on Germanium on insulator: fabrication, properties and applications

Antoine Pedeches is starting a PhD at CRHEA in the team Opto under the supervision of Fabrice Semond and Hélène Rotella.
Subject: Epitaxy and study of the properties of hybrid materials

November

Sandeep Yadav Golla defends his doctoral work on "The conformal metasurface: synthesis and applications".

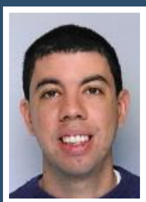
This year, CRHEA carried out its first carbon assessments for the years 2019 and 2020 by adhering to the assessment tool of Labo1.5. This approach aims to better understand and reduce the impact of scientific research activities on the environment. Thanks to the reduction in travel caused by the health situation, CRHEA's overall carbon impact fell by 20% in 2020 compared to 2019.

2021
ADVANCEMENT / PRIZE

MT180: An award-winning CRHEA student .

Max Meunier shows his price

The Côte d'Azur University organized the 8th local edition of the national competition "My thesis in 180 seconds" on Wednesday March 17th, live from the Maison de l'Etudiant. Max Meunier, PhD at CRHEA, is one of the two first prize winner of the jury and represented the Université Côte d´Azur in the semi-finals on April 1st.



Aimeric Courville promotion as « Ingénieur d'Etudes ».

Julien Brault promotion as CNRS senior research associate «Directeur de Recherche2»

Sébastien Chenot promotion as research engineer « Ingénieur de Recherche ».

ELECTRO

In spite of difficulties related to the pandemic situation, the research activities around materials for electronic applications did not collapse in 2021. On the contrary, studies on the CVD growth of cubic SiC led to innovatives processes for the fabrication of ultra-sonic sensors and nano-strain-meters, the first tests of a new reactor for high temperature CVD growth of nitrides have started, the growth of Vanadium doped highly resistive SiC was studied with NOVASiC, the ANR project BREAkuP has shown the interest of ultra-wide bandgap III-Nitrides for high power applications, promising results on RF losses and in-situ passivation of MBE grown GaN-on-Si HEMTs have been obtained in the frame of the project Hypergan, a collaboration with the start-up Easygan and further progress was achieved for the co-integration of E-mode with D-mode GaN HEMTs in the frame of the ANR project ED-GaN.
On the other hand, Nano 2022 actions in collaboration with STMicroelectronics and SOITEC were pursued on GaN and SiC for power electronics, while 4 new projects started with the support of the labex GaNeXT in addition to the H2020-ECSEL project GaN4AP dedicated to GaN power electronics. 4 PhD thesis have started on topics like ScAlN/GaN HEMTs (GaNeXT), high breakdown voltage HEMTs (coll. EXAGAN), vertical GaN-on-Si devices (coll. LETI) and Graphene on Germanium (coll. IM2NP). Just to say that this second annus horribilis was not so bad and full of hopes for research activies in materials for electronics.

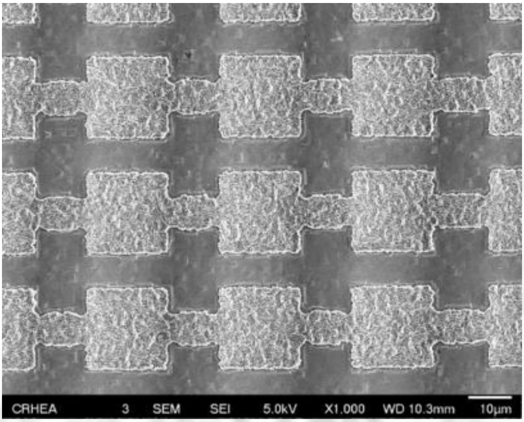
Yvon CORDIER, head of ELECTRO

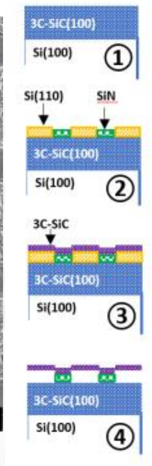
3C-SiC For Ultrasonic Sensors

Towards highly sensitive 3C-SiC strain sensors for geo-sciences

Co-integration of E/D mode GaN HEMTs

GaN4AP





Left: *a scanning electron microscope image of a CMUT-based structure fabricated at CRHEA. The visible square shaped cells correspond to uppermost 3C-SiC film, dedicated to form a suspended membrane.*

Right: *schematic representation of the different deposition steps required for obtaining a suspended membrane.*

3C-SiC For Ultrasonic Sensors

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IMPACT

An innovative approach for designing harsh environment sensors.

RESEARCH PARTNERS :

- H2MEMS project consortium: IMS, GREMAN, LAAS, CRHEA

Ultrasonic sensors are widely spread for imaging applications, especially in the medical and industry fields, and for sensing chemical environments.

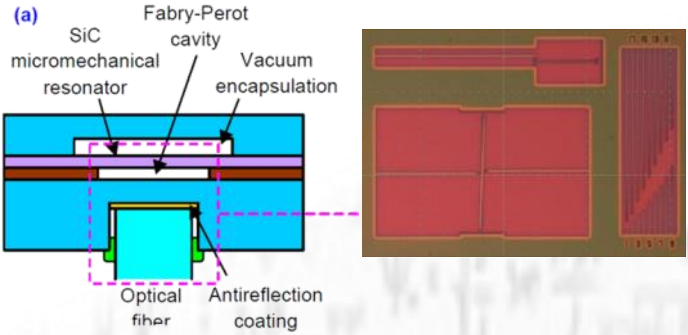
The base principle of such sensors often relies on micrometer-sized resonating membranes, able to produce or sense ultrasonic waves. Currently, a growing demand arises for improving such sensors for being operated under aggressive environments, in terms of temperature or radiations.

The choice of the resonating membrane material is also crucial for designing a robust device, which won't degrade under the working conditions.

According to very good mechanical properties, robustness under radiations, and chemical inertness, innovative 3C-SiC-based ultrasonic resonating membranes, are developed by epitaxy at CRHEA within the scope of the H2MEMS project (ANDRA PIA3 –2017-2022) which aims at fabricating robust sensors on cheap silicon platforms.

FURTHER READING :

- *« Designing SiC Based CMUT Structures: An Original Approach and Related Material Issues »*, M. Portail, S. Chenot, M. Ghorbhanzadeh-Bariran, R. Khazaka, L. Nguyen, D. Alquier and J.-F. Michaud, to be published in Materials Science Forum.



◀ *(LEFT) Schematic of the strain sensor concept: 3C-SiC resonator oscillation is actuated by modulating incoming laser light intensity. The shift of resonance frequency is proportional to applied strain. A second laser is used to detect the oscillations by interferometry measurements.*

(RIGHT) optical microscopy image of released strain gauges and double clamped beams used for strain and stress evaluation in the epilayer.

Towards highly sensitive 3C-SiC strain sensors for geo-sciences

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IMPACT

Novel concept of highly sensitive 3C-SiC resonating strain sensor, with optical actuation and optical state readout for applications in geo-sciences.

RESEARCH PARTNERS :

• SiC Nano for PicoGeo partners: NOVASiC, CNR IMM Catania (Coordination), CNR IMM Bologna.
Project funding from the European Union's Horizon 2020 R&I programme, grant agreement N° 863220

SiC Nano for PicoGeo consortium targets the development and testing of new strain sensor concept with high-precision capabilities (< 10^{-12}) that will offer the opportunity of detecting extremely small strain signals that precede and accompany seismic events and volcanic eruptions.

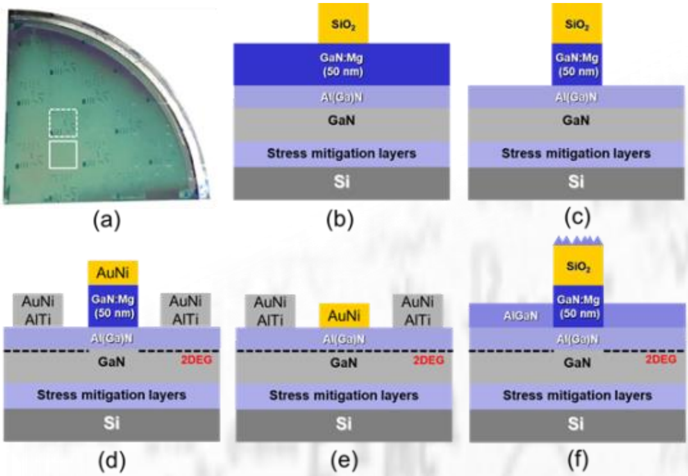
Upstream of sensor design and manufacturing, NOVASiC cooperated with CRHEA CNRS on development of growth processes allowing the controlled deposition of 3C-SiC layers strongly doped with nitrogen, aluminum and vanadium. The mechanical properties (stress, strain and elastic modulus) of 3C-SiC layers with different doping types, grown on (100) and (111) oriented Si substrates, were then studied by project partners. The measurement of resonance frequency of double clamped beam gives us the information on residual stress. Independently, the analysis of deformation of strain gauges allows the strain determination. By combining both results, Young's modulus can be extracted from Hooke's law.

Despite low thickness (<1µm) of the analyzed 3C-SiC epilayers, relatively high values of Young's modulus (up to 500GPa) could be obtained opening the path to the fabrication of very sensitive strain sensors.

FURTHER READING :

SiC Nano for PicoGeo website: http://picogeo.eu

Sergio Sapienza et al, Micromachines 2021, 12(9), 1072, doi.org/10.3390/mi12091072



Schematic of the fabrication process enabling the co-integration of E-mode with D-mode GaN HEMTs : (a) photograph of the quarter wafer with SiO_2 patterned for E-mode and D-mode devices; (b) Definition of the E-mode gate pattern on the initial epi-layers covered with SiO_2; (c) sublimation of the p-GaN cap; (d) fabrication of an E-mode transistor; (e) fabrication of a D-mode transistor; (f) alternative process with regrowth of AlGaN after p-GaN sublimation.

Co-integration of E/D mode GaN HEMTs

Authors:

Thi Huong Ngo,
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IMPACT

An innovative approach to fabricate E-mode GaN transistors and to co-integrate them with D-mode ones.

High electron mobility transistors (HEMTs) based on the AlGaN/GaN heterostructure have shown interests in many power applications that benefit from outstanding properties of GaN material such as high breakdown voltage, high electron velocity and good thermal conductivity. To date, the main successes in GaN electronics have been obtained with depletion-mode (D-mode) devices. Implementation of enhancement-mode (E-mode) transistors, which is much more difficult to achieve, is one of the biggest challenges to fulfilling the functionality of GaN HEMTs. In the present work, we developped a solution based on the sublimation of p-GaN cap layers to fabricate E-mode transistors with V_{th}>1.5 V without any electrical degradation impacting the device performance. More, we demonstrated the co-integration with D-mode devices as well as the increase of transistor performances thanks to the regrowth of AlGaN layers.

RESEARCH PARTNERS :

- ED-GaN ANR project consortium: LN2, IEMN, IMS, OMMIC.

FURTHER READING :

- Thi Huong Ngo et al, Semicond. Sci. Technol. 36 (2020) 024001, DOI: /10.1088/1361-6641/abcbd3
- Thi Huong Ngo et al, Solid-State Electronics 188 (2022) 108210, DOI: /10.1016/j.sse.2021.108210

GaN4AP (Gallium Nitride for Advanced Power Applications), funded in the framework of the EU call H2020-ECSEL-2020-1-IA, was launched in June 2021 by the ECSEL JU, the Public-Private Partnership keeping Europe at the forefront of technology development.

New European Project on Disruptive GaN Power Electronics Applications

Authors:

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IMPACT

Benchmarking of GaN substrates, demonstration of the interest of Molecular Beam Epitaxy for ScAlN/GaN HEMTs, for the control of p-type doping in GaN and for the growth AlN nucleation layers on Silicon.

Efficient power conversion systems have become the heart of the worldwide efforts for energy transition and a green economy, since they can minimize losses and save energy, contributing to a reduction in the emission of CO_2. Wide band gap semiconductors, such as Gallium Nitride (GaN), have outstanding properties enabling system designers to operate them at higher voltages, temperatures, and switching frequencies, with larger efficiency gains with respect to the traditional Silicon devices. GaN4AP links private companies, universities, and public research institutes working in the field of GaN materials, devices, and related applications. The Consortium is composed of 36 members from 6 different European countries. The GaN4AP project has the ambitious target of making GaN-based electronics one of the main components in a large spectrum of power converter systems. To achieve this goal, GaN4AP will push the boundaries of GaN-based technology by studying: (i) Power conversion systems based on state-of-the-art GaN-based HEMTs; (ii) Novel AlScN materials for high-current and high-power HEMTs; (iii) New generation of vertical power devices based on bulk GaN; (iv) Intelligent and integrated GaN power converters solutions for e-Mobility.

RESEARCH PARTNERS :

- DTSMNS, CNR-IMM, Univ. Tours, CEA Leti, IHPP, FBH, Fraunhofer IAF ...
- Freiberger, Aixtron, STMicroelectronics, NXP, Valeo-Siemens, Schneider Electric, APSi3D, ...

FURTHER READING :

- www.gan4ap-project.org

NANO

2021 has been rich in human changes for the Nano team. First, with the arrival of 3 new permanent staff members: Hélène Rotella as a research associate whose activities focus on the epitaxy of zinc and magnesium oxynitrides ZnMgNO, a new family of materials for applications in transparent electronic circuits and solar cells. Significant advances were published this year on this topic; Pierre-Marie Coulon as a research engineer, who has taken in charge the Thomas Swan MOCVD growth reactor on which many projects rely, including the work of 4 PhD students. Finally, Minh Tuan Dau, recruited as associate professor at UCA and as a specialist in the MBE growth of 2D materials.

2021 also saw the departure of Jesus Zuniga Perez on a 2 year secondment to Nanyang Technological University (NTU) in Singapore, where he is working on quantum optics. Good luck Jesus !

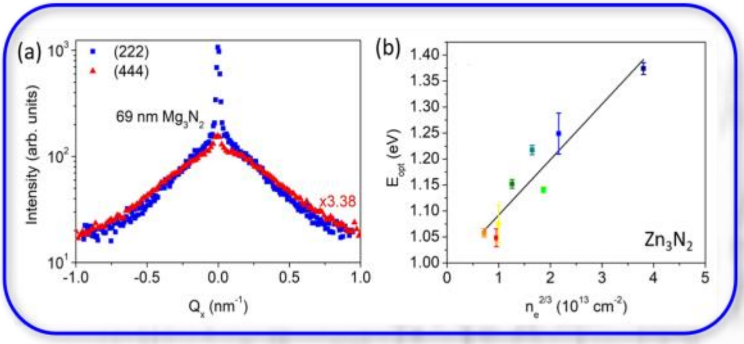
Finally, remarkable results have been obtained by the metasurfaces activity led by Patrice Genevet, published in high–ranking journals. The ability of metasurfaces to manipulate light wavefronts can be used in multiple systems, such as the LIDAR developed within the team.

Blandine Alloing, head of NANO

New nitride materials: Zn_3N_2 and Mg_3N_2

Upon Reflection, Modulate Phase

Compensating optical aberrations with metasurfaces



Structural and optoelectronic properties of epitaxial Mg_3N_2 and Zn_3N_2: (a) XRD rocking curve of a Mg_3N_2 thin film displaying two components: a resolution-limited contribution and the « standard » tilt contribution; (b) Moss-Burstein shift in a series

New nitride materials: Zn_3N_2 and Mg_3N_2

Authors:
Philipp John,
Hélène Rotella,
Mohammed Al-Khalfioui,
Sébastien Chenot,
Christiane Deparis,
Maxime Hugues,
Philippe Vennéguès.

In the quest of new semiconductors it is essential to fabricate high-quality materials to insure the measurement of fundamental physical properties is not perturbed by defects.

In the last two years we have grown for the first time single crystalline Mg_3N_2 and Zn_3N_2 thin films by molecular beam epitaxy. We have now measured their structural properties, including their lattice parameters and thermal expansion coefficients, which are three times larger than those of AlGaInN. With the aim of exploiting them in optoelectronic devices we have further determined their fundamental electronic properties: their optical bandgaps span the range from about 1eV (for Zn_3N_2) to about 3eV (for Mg_3N_2), while in terms of electrical conductivity they go from insulating material (Mg_3N_2) to highly conducting material (Zn_3N_2), with a record electron mobility of ~400cm^2/Vs at room-temperature.

IMPACT

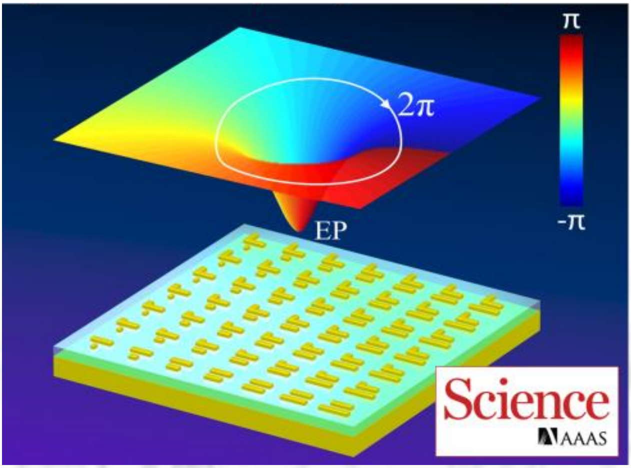
Mg_3N_2 and Zn_3N_2 were the two lacking ingredients of the larger ZnMg-oxynitride materials family. Their epitaxial growth opens the door to exploit this new family of materials for their semiconducting properties in devices going from solar cells to UV-emitting devices.

RESEARCH PARTNERS :

- Prof. M. Grundmann, Felix-Bloch-Institut für Festkörperphysik, Universität Leipzig, Germany
- Dr. C. Lichtensteiger, University of Geneva, Switzerland

FURTHER READING :

- P. John et al., Journal of Applied Physics **130**, 065104 (2021)
- P. John et al., Journal of Applied Physics **129**, 095303 (2021)
- P. John et al., Physical Review Materials **4**, 054601 (2020)



Upon Reflection, Modulate Phase

Authors:

Qinghua Song,
Mutasem Odeh,
Jesús Zúñiga-Pérez,
Boubacar Kanté,
and Patrice Genevet

IMPACT

The realization of optical interfaces relying on topological phase prove that metasurface technology represents a convenient test bench to study and validate topological photonic concepts.

Optical Metasurfaces are optical interfaces composed of subwavelength structures to engineer amplitude, phase and polarization of the transmitted/reflected light. Recognizing that metasurfaces are also open systems interacting with their environment, associated tranfert matrices are non-Hermitian, which provides rich physical behavior, in partcular in the vicinity of singularities.

Singularities manifest when a given channel connecting input and output light beams is extinguished. The amplitude of the light wave goes to zero and its phase is no longer defined at a given point of the nanostructure parameter space. Encircling this singular point in the parameter space, i.e. by continuously varying the object geometry, a 2π phase shift of topological nature is revealed.

We designed a metasurface that exploits those non-Hermitian properties such that they can encircle an exceptional point, thus providing an additional control knob in designing metasurfaces for wave front engineering.

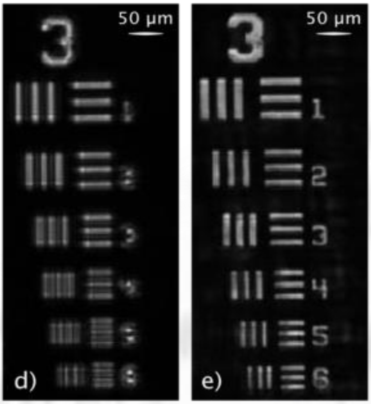
RESEARCH PARTNERS :

- Department of Electrical Engineering and Computer Sciences, University of California, Berkeley, CA 94720, USA

FURTHER READING :

- « *Plasmonic topological metasurface by encircling an exceptional point* », Q Song, M Odeh, J Zúñiga-Pérez, B Kanté, P Genevet, **Science** 373 (6559), 1133-1137 (2021)

Compensating optical aberrations with metasurfaces



Normal Lens   Corrected metalens

Authors:
Rajath Sawant,
Daniel Andrén,
Renato Juliano Martins,
Samira Khadir,
Ruggero Verre,
Mikael Käll
and Patrice Genevet

IMPACT

The possibilities of adjusting arbitrary spatial amplitude, phase, polarization, and dispersion profiles with hybrid metasurfaces offer unprecedented optical design opportunities for compact and broadband imaging, augmented reality/virtual.

Refractive lenses are extensively used in imaging systems such as cameras, microscopes, telescopes etc. The ability of lenses to converge or diverge the optical ray trajectories is conferred to the material by its curvature and thickness.

Most of the refractive components suffer from optical aberrations, generally classified in two main categories, namely monochromatic and chromatic. This results in distorted images, limiting the resolution and performance of imaging systems.

We realized experimentally a centimeter-scale aberration-compensated optical system, which is suitable for commercial applications, using a hybrid refractive-diffractive metasurface approach. We showed that its combination with existing refractive optics can compensate for both spherical and chromatic aberration of refractive commercial lens system.

We demonstrated aberration-correction of at least 80% for chromatic aberration and 70% for spherical aberration. We also took monochromatic and achromatic images that clearly show how these hybrid systems outperform standard refractive lenses. The results are presented in panel figure showing, on the left, an image obtained with a refractive lens, and on the right, the same object imaged using a metasurface to compensate for spherical aberrations.

RESEARCH PARTNERS :

- Department of Physics, Chalmers University

FURTHER READING :

- « *Aberration-corrected large-scale hybrid metalenses* », R Sawant, D Andrén, RJ Martins, S Khadir, R Verre, M Käll, and P Genevet, **Optica** 8 (11), 1405-1411 (2021)

OPTO

2021 has brought its share of changes, successes, and renewal within the OPTO team. Jean-Michel Chauveau obtained a Professor position and joined the Group for the Study of Condensed Matter (GEMaC) at the University of Versailles Saint-Quentin (UVSQ). We had the pleasure of welcoming Antoine Pedeches (Master internship) and Nikita Nikitskiy (thesis) to work on "quantum dots" and "electroluminescent metasurfaces" in collaboration with the NANO team. Sébastien Tamariz (post-doc) also joined us to work on the "epitaxy of nitride materials on silicon substrate" on an MBE reactor (MBE 49) working on industry compatible wafers.

The research activity, which primarily focuses on the optical and optoelectronic properties of III-nitride and II-oxide semiconductors has seen impressive results in particular in the framework of selective sublimation process for nanoporous nitride semiconductors and/or nanowires (ANR project NAPOLI), and ultra-violet light emitting diodes with tunnel junctions (ANR project DUVET and GANEX Labex). Recently, a hot topic has emerged with the fabrication and integration of niobium nitride (NbN) superconductors on III-nitrides which will be the subject thesis of Antoine Pedeches in the framework of an ANR project (NIOBIUM).

Julien Brault, head of OPTO

Ultra-violet (UV) Light Emitting Diodes

Niobium nitride (NbN)-based superconductors

UV LED (285 nm) measured in a probe station

UV LEDs for sterilization applications

Authors:

Jean-Yves Duboz,
Julien Brault,
Benjamin Damilano,
Victor Fan Arcara,
Aly Zaiter.

IMPACT

Water purification remains one major concern for a large part of humanity. This is obviously the case in many third world countries, but not only. In some remote places, accessing a permanent or temporary system of water treatment, with immediate action, contrary to chlore treatment for instance, would be a tremendous asset.

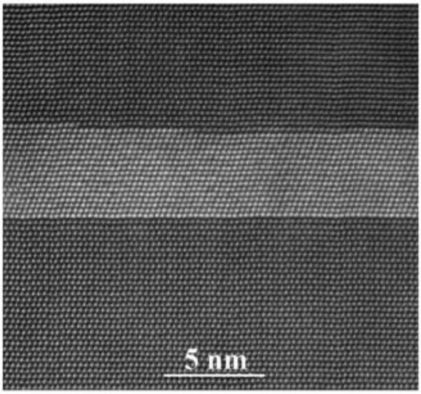
Below the wavelength of 280 nm, there is no natural UV radiation on earth. Related to this, molecules of living species, in particular DNA, are degraded under these UVC radiation, which can be used to eliminate bacteria and virus by stopping their replication. One can modify the composition of the material (GaN) used for fabricating LED used for solid state lighting, by introducing some aluminium in order to get the AlGaN semiconductor, which emits in the UV range. In practice, it is not so simple, and we have to face many challenges on the growth of this alloy, on the doping (introduce positive and negative charges in the material). Quantum mechanics fortunately help us in solving some of these challenges. For instance, the tunnel effect, a pure quantum effect, is used to transform negative charges into positives ones! Finally, we got LED emitting in the UV. So far, there are not efficient enough: while ideally one electron injected in the LED should allow emitting one UV photon, we could get only 2% of the expected photons. There is obviously room for improvement, and our goal is to reach 10 times more in order to be able to fabricate useful systems.

RESEARCH PARTNERS :

- LETI Grenoble, Tech. Univ. Berlin UMI-GT Metz, L2C Montpellier.
- UMI-GT Metz, L2C Montpellier.

FURTHER READING :

- Les diodes électroluminescentes: les nouvelles sources pour l’émission UV, Reflet de la physique n° 7, January 2022
- V. Fan Arcara et al, Ge doped GaN and $Al_{0.5}Ga_{0.5}N$-based tunnel junctions on top of visible and UV light emitting diodes, J. of Appl. Phys. **126**, 224503 (2019).



GaN/NbN/GaN epitaxially grown on a silicon substrate by NH3-MBE observed by high resolution transmission electron microscopy (Courtesy of P. Ruterana et al., CIMAP)

Epitaxy of Niobium Nitride Metal/Semiconductor/Superconductor Heterostructures

Authors:

Fabrice Semond, Hélène Rotella, Antoine Pedeches, Yvon Cordier, Jean-Yves Duboz, Eric Frayssinet, Maxime Hugues , Philippe Vennéguès.

IMPACT

Original metal / semiconductor, superconductor / semiconductor heterostructures grown by epitaxy for quantum technologies, high frequency components and photonics.

Niobium nitride (NbN) is an electrically conductive material which becomes superconducting below 17K. Its superconducting properties are already widely used for the realization of single photon detectors and superconducting Qubits. Recent works show that NbN can be obtained by epitaxy on (Al,Ga)N, and vice versa. However, NbN has multiple crystalline phases and stoichiometries which significantly influence its physical properties. On the strength of our experience in gas phase molecular beam epitaxy of III-nitrides, we are starting a new activity dedicated to NbN epitaxy. The objective is to develop growth processes to get an extreme control of various new NbN / III-N heterostructures in order to combine Metal/Semiconductor/ Superconductor properties to highlight improved or new physical phenomena.

RESEARCH PARTNERS :

- 3-5Lab, CIMAP - high frequency transistors (ANR Niobium)
- INPHYNI – Quantum Photonics
- Looking for partners (single photon detectors, proximity effects, qubit superconductor, …)

COMMON RESEARCH SERVICE

The Common Research Service provides a highly skilled platform for all the research activities of the laboratory, based on a large set of material characterizations techniques and a technological platform, member of the Renatech+ national network.

Assuming a long-term mission, SCR has continued in 2021 to provide its high level expertise for supporting both historical scientific thematics as well as new material developments, as ScAlN and NbN.

2021 has been also highlighted by a major event. The acquisition, by the laboratory, of a SPECTRA200 HR-TEM facility, provides a unique tool for decisive structural analysis for research groups and for external partners. It's a delight to discover this new equipment in a special highlight. This instrument is operated by the SCR UCA team and is a part of Material Advanced Characterisation platform (ACTM) .

Finally, on top of day-to-day supports to the diverse research activities, SCR contributes to feed CRHEA's material expertise with original works, presently reported.

Hoping you will enjoy!

Maud Nemoz, head of SCR

ACT-M

SPECTRA 200

a new

High Resolution STEM at CRHEA

Interdiffusion in

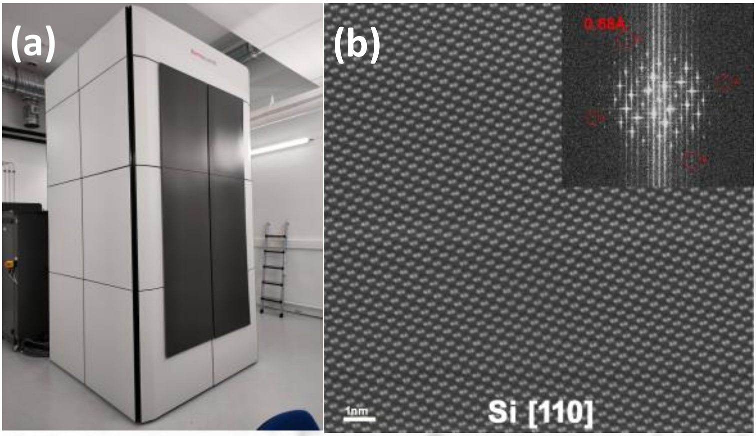
AlN/AlGaN

superlattices

O-RETURN:

Analysing

Bennu's samples



◀ *(a) Photo af the Spectra 200 protected by its enclosure (b) High resolution HAADF image of Silicon [110]: Si dumbles are clearly separated; in inset the FFT shows a spatial resolution down to 0.68 Å.*

ACT-M SPECTRA 200 a new High Resolution STEM at CRHEA

Authors:

Philippe Vennéguès, Hélène Rotella.

IMPACT

The new state-of-the-art ACT-M STEM is an essential tool for researchers and engineers working on the very competitive field of the development of innovative materials.

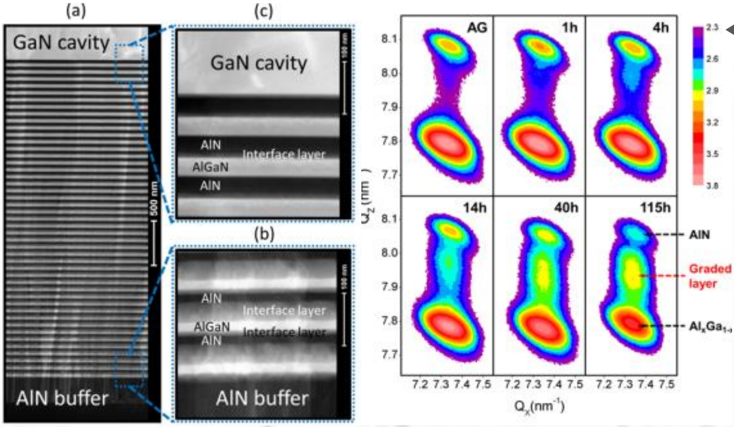
Structural and chemical characterizations of materials at the atomic scale are fundamental to comprehend their physical properties. The success of the ACT-M project, regrouping 7 academic laboratories and one company, coordinated by the CRHEA, led to the acquisition of a state-of-the art scanning transmission electron microscope Thermo Fishers Spectra 200, thanks to the financial support of CNRS, University Côte d'Azur, region Sud, IMRA Europe and European funding (FEDER). This cold-FEG STEM, operational from January 2022, is equipped with a probe corrector achieving a spatial resolution below 70pm. An energy dispersive X-ray spectrometer is implemented in the system using two large detectors (solid angle of 1.8 sr) allowing high sensibility chemical analysis. Finally, the ACT-M STEM is equipped with a nanodiffraction module including the precession to realize phase and orientation cartography. This tool is open to any academic lab and company which want to take advantage of its ultimate performances.

RESEARCH PARTNERS :

- IMRA Europe
- CEMEF; INPHYNI; CCMA; GEOAZUR; CEPAM; LAGRANGE

FURTHER READING :

- CNRS-CRHEA | ACT-M



Interdiffusion process in $AlN/Al_{0.3}Ga_{0.7}N$ superlattices.
Left: $(AlN/Al_{0.3}Ga_{0.7}N)_{45}$ SL with interfaces sharper at the top than at the bottom after a 24h-growth at 800° C.
Right: $(AlN/Al_{0.3}Ga_{0.7}N)_5$ SL after 1 hour to 115 hours annealings at 800°C. The increase of the graded layer peak intensity illustrates the interdiffusion process in the SL.

Interdiffusion in AlN/AlGaN superlattices

Authors :
Maud Nemoz,
Fabrice Semond,
Stéphanie Rennesson,
Mathieu Leroux,
Sophie Bouchoule,
Gilles Patriarche,
Jesus Zuniga-Perez.

Diffusion at the $AlN/Al_{0.3}Ga_{0.7}N$ interface was investigated by X-ray diffraction, high-angle annular dark field scanning transmission electron microscopy and energy-dispersive X-ray spectroscopy. $AlN/Al_{0.3}Ga_{0.7}N$ superlattices (SLs) have been grown at 800 °C on (111) silicon substrates by ammonia-assisted molecular beam epitaxy. Annealings on a 5-pair SL, carried out at the growth temperature in an ammonia-based atmosphere from 1h to 115h, show the occurrence of a diffusion process illustrated by the increase of the interface layer thickness.

The effect of the unintentional annealing of buried layers during long growth runs is exemplified on a 45-pair SL. The measurement of the actual composition profile along the growth direction shows the formation of an unintentional AlGaN graded layer of intermediate composition at each interface. The thickness of each of these interfacial layers is found to decrease along the SL growth direction, pointing towards the influence of the overall time spent at growth temperature as a determining parameter.

IMPACT

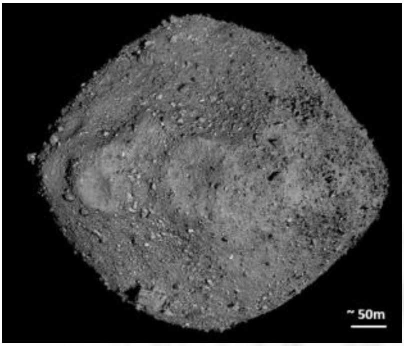
This interface layer is probably present in other AlN/AlGaN structures. Reducing or eliminating this interface layer may be critical for some electronic or optoelectronic applications for which abrupt interfaces are required.

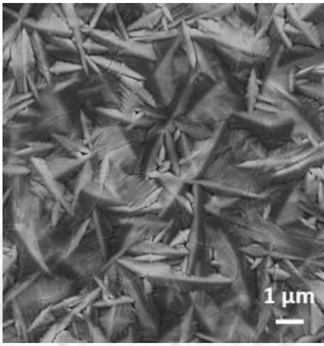
RESEARCH PARTNERS :

- C2N,CNRS.

FURTHER READING :

https://doi.org/10.1016/j.spmi.2020.106801





Left : a mosaic of Bennu, created using observations made by NASA's OSIRIS-REx spacecraft that was in close proximity to the asteroid for over the two last years. Credit: NASA/Goddard/ University of Arizona

Right: a synthetic forsterite sample, one of the meteor-ites constituent, synthetized at CRHEA.

O-RETURN: Analysing Bennu's Samples

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IMPACT

An Material Science-Cosmochemistry inter-disciplinary project.

A new look at primordial components of our Solar System.

The O-RETURN project has been launched in October 2021 for preparing the return of the NASA's OSIRIS-Rex mission. Having collected, in December 2020, surface samples of a very primitive asteroid, BENNU, the OSIRIS-Rex spacecraft has started its return journey to Earth for delivering its invaluable samples on September 2023. International efforts will be needed for analyzing these samples which witness the very early age of our Solar System.

Including two partners, LAGRANGE and CRHEA, O-RETURN has been granted, for four years, by the ANR for developing analytical methods for deciphering the history of some very pristine constituents enclosed in the collected samples.

The CRHEA will fabricate synthetic standards for quantitative luminescence analysis and will conduct spectroscopic investigations on the collected samples.

RESEARCH PARTNERS :

- LAGRANGE Laboratory, UMR 7293 - CNRS-OCA-UCA, Coordinator of the project

FURTHER READING :

- *« Chondrules as direct thermomechanical sensors of solar protoplanetary disk gas »*
  G. Libourel, M. Portail, Science Advances 4, eaar3321 (2018).

CRHEA

Centre de Recherche

sur

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